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ANTIMONY-124: ITS SOURCE AND BEHAVIOUR UNDER CAN-DECON CONDITIONS

Report No. 87-69-K

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ABSTRACT

The deposition of antimony-124 (Sb-124) on various PHT surfaces led to high post-decontamination fields. It was found that highly active cruds containing Sb-124 were briefly released from the core shortly after the first chemical injection during a CAN-DECON decontamination. In addition, Sb-124 was also released from boilers. Sb-124 is mainly produced by the neutron activation of Sb-123 found naturally in the antimony which is a very minor component in the pressure tube and fuel sheath materials. The inventory of Sb-124 in a Bruce reactor was estimated to be about 1100 Ci. The behaviour of Sb-124 during several decontaminations was also summarized. Future work to study methods to mobilize Sb-124 and subsequently to cleanup the waste stream is recommended.

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EXECUTIVE SUMMARY

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The deposition of antimony-124 (Sb-124) on various PHT surfaces led to high post-decontamination fields in the 1981 Pickering 1 and 1986 Bruce 1 decontaminations. Sb-124 could possibly be produced in a CANDU reactor by neutron activation of antimony or tin, and both elements were found in most of the PHT test specimens. The results of the gamma spectrometry of pressure tube specimens showed that two known activation products from tin were found only on the Zircaloy 2 pressure tube, but not on the zirconium-niobium tube whereas Sb-124 was found on both materials. Furthermore, the ratio of Sb-124 to a tin activation product found on a station specimen did not agree with the value predicted by the Origen code for tin activation suggesting that Sb-124 is most likely not produced from tin. In addition, the concentration of antimony in the pressure tube (Zr/Nb) specimen required for the observed Sb-124 activity was quite close to the concentration of antimony found in the two pressure tube specimens. These results indicate that Sb-124 is mainly produced by the neutron activation of antimony (Sb-123) in pressure tubes and fuel sheaths. The Sb-123 in the corrosion products released from other parts of the circuit eg from boilers could also be activated in the core. Cruds containing Sb-124 could subsequently deposit onto other PHT surfaces.

The inventory of Sb-124 in a Bruce reactor was estimated to be about 1100 Ci.

Zirconium dioxide and tin oxides were only found in a highly active crud collected shortly after the first chemical injection during the recent Bruce decontamination suggesting that cruds from the core were briefly released during a decontamination. Release of Sb-124 from the boilers was also observed by gamma spectrometry.

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Data on Sb-124 behaviour during several decontaminations was gathered and showed that Sb-124 could be partly removed by a filter, but not by the cation exchange resin.

Future work to investigate methods to mobilize Sb-124 from the PHT surfaces and to subsequently remove Sb-124 from the coolant is recommended.

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To Dr. D. Mills
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ANTIMONY-124: ITS SOURCE AND BEHAVIOUR UNDER CAN-DECON CONDITIONS

BACKGROUND

Various amounts of antimony-124 (Sb-124) have been deposited on PHT surfaces in previous CAN-DECON decontaminations, and sometimes Sb-124 played a major role in determining the outcome of the decontaminations. For example, in the decontamination at Bruce Unit 1, the Co-60 radiation field at the reactor face decreased from 67 to 37 mR/h, but the Sb-124 field increased from 16 to 53 mR/h, thus the overall field remained unchanged (about 97 mR/h) after the decontamination/1/. A similar phenomenon was also observed in the earlier Pickering Unit 1 decontamination. This feature resulted in studies being initiated to gain a better understanding of the source of Sb-124, and the behaviour of Sb-124 under CAN-DECON conditions. In addition, the inventory of Sb-124 in a Bruce reactor was estimated.

RESULTS AND DISCUSSION

1. SOURCE OF Sb-124

In a CANDU reactor, Sb-124 with a half life of 60.2 d is mainly produced by the thermal neutron activation of Sb-123 present in the metal. Sb-123 (i) can be found naturally in antimony, or (ii) is the product of the beta decay of tin-123 (Sn-123) which in turn is formed by the activation of the Sn-122 in tin[1]. In other words, the production of Sb-124 requires the presence of antimony or tin in the core. Therefore, to identify the source of Sb-124 (i) the concentration of antimony and tin in various station components was calculated and/or determined analytically,

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1 Isotopes that can be found naturally in tin include Sn-112, 114, 115, 116, 117, 118, 119, 120, 122 & 124.

and (ii) the concentration of Sb-124 was compared to the concentration of another activation product of tin, namely Sb-125 (Sb-125 is the product of the beta decay of Sn-125 which is formed by the activation of the Sn-124 in tin).

The calculation employed was mainly based on gamma spectrometry results of the in-core base metal from CRNL/2/ and the assumption that isotopes with half lives significantly less than the exposure time of the specimens to the operating conditions reached saturation activities in the base metal before the specimen removal. This includes Sb-124, Sb-125, Sn-113 (also an activation product of tin) and Zr-95.

In addition, neutron activation analysis (NAA) and inductively coupled plasma (ICP^2) were used to determine the antimony and tin content in several specimens including pressure tube (Zircaloy 2, & zirconium with 2.5% niobium (Zr/Nb)) and fuel sheath (Zircaloy 4) materials, as well as specimens from out of core components - feeder (carbon steel) and boiler tube (Inconel 600), because the corrosion products released from these components could have been activated in the core.

Table 1 lists the calculated and experimental results on the antimony and tin content of the specimens.

1.1 Zircaloy 2 Pressure Tube (Pickering 1 & 2)

The antimony content of a Pickering 2 G16 pressure tube section removed in 1983 (base metal) was estimated to be only 40 ppm to account for the Sb-124 in the pressure tube. In addition, the calculated activity ratio between Sn-113 and Sb-125 agreed very well with the value found in the same specimen. Furthermore, the calculation was also supported by the fairly good agreement between the calculated tin content of the Zircaloy 2 (2.1%) and the value from the specification of the material (1.2% to 1.7%).

It should be noted that the calculated value will likely be overestimated because it was assumed that all of the neutrons were thermalized in the pressure tubes, but actually this will not be the case.

The Origen code predicted that if Sb-124 is produced by double activation of tin, the ratio between activity of Sb-124 and Sb-125 would be 1 to 24 in the in-core materials /3/, but the actual ratio found in the base metal of the Pickering 2 G16 pressure tube sample was only 1 to 3 at the time of removal/2/. This suggests that tin is unlikely to be the source of Sb-124.

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2 ICP provides the average composition of the surface of a specimen.

1.2 Zirconium with 2.5% Niobium Pressure Tube

From the Sb-124 and Zr-95 activity of a Pickering 3 pressure tube sample, it was calculated that the antimony content of this pressure tube would have to be 7 ppm to account for the Sb-124. This calculated antimony content is quite close to the values actually found on a Bruce 2 pressure tube (3 ppm) and a Pickering 5 pressure tube (1 ppm) samples by NAA /4/ suggesting antimony is a possible source of Sb-124.

In addition, only Sb-124, but not the longer lived Sb-125 was observed in the Pickering 3 pressure tube sample/2/ suggesting the source of these two isotopes is not related. (ie tin is likely not the source of Sb-124).

The tin content of Bruce 2 and Pickering 5 pressure tube specimens was below the detection limit of NAA (20 ppm)/4/.

1.3 Fuel Sheath (Zircaloy 4)

The tin and antimony content of a fuel sheath sample was found to be 0.7% and 2 ppm, respectively by NAA /4/.

1.4 End Fitting (stainless steel 410 or 403)

The antimony content of the base metal of a Bruce 2 end fitting liner and a Pickering 2 end fitting body was found to be 30 and 60 ppm, respectively, by ICP/5/. The tin content of both samples was 50 ppm /5/.

Assuming that Fe-59 and Sb-124 reached saturation activity before the removal of a Bruce 2 end fitting/2/ and the iron content of the base metal was 880 g/kg, it was estimated that the antimony content of the base metal was about 200 ppm.

1.5 Carbon Steel and Inconel 600

The antimony content of a Bruce carbon steel specimen (ASME A106 Grade B) and a Bruce 1 steam generator tube (Inconel 600) specimen was found to be 100 and 4000 ppm by ICP/5/. The antimony content of the steam generator tube specimen was unexpectedly high (The specification of Inconel 600 does not include the amount of antimony allowed in it) and was confirmed by atomic absorption/5/.

The tin content of both samples was below the detection limit of ICP (10 ppm)/5/.

Antimony and tin were found in most of the specimens, but the amount of Sb-124 and Sb-125 in various specimens indicates that the major source of Sb-124 in a CANDU reactor is from the neutron activation of Sb-123 present in the in-core materials. In addition, the Sb-123 in the corrosion products released from

other parts of the circuit eg from boilers could possibly be activated in the core. Cruds containing Sb-124 may subsequently deposit onto other PHT surfaces.

2. Sb-124 INVENTORY

The Sb-124 inventory in a Bruce reactor core was calculated based on (i) the result from the Origen code which showed that 3.36 g of Sb-123 would produce 100 Ci Sb-124 in the core/3/, and (ii) the average antimony content of both pressure tube and fuel sheath found in the specimens is 2 ppm (from previous sections). The Sb-124 inventory in the base metal of the pressure tubes and fuel sheaths was found to be 740 Ci and 350 Ci, respectively.

In addition, Sb-124 can also be present in the oxide grown on the pressure tubes. Hence, in order to estimate the Sb-124 inventory in the oxide, it is necessary to know the amount of oxide on the pressure tubes and its specific activity. It was reported that the average oxide thickness on a Bruce Zr/Nb pressure tube was about 10 μm/6/, hence, the total oxide inventory on the Bruce pressure tubes was estimated to be 60 kg by assuming that the density of the oxide is same as the pure zirconium dioxide (5.89 g/cm^3). It is believed that the highly active cruds collected in the very early stage of the Bruce Unit 1 CAN-DECON decontamination were released from the core (see section 3.1), hence, the average Sb-124 specific activity of the cruds (150 mCi/kg) collected during that time was used in the estimate. The results show that there are about 9 Ci of Sb-124 in the oxide on the pressure tubes. Similar calculations for oxide grown on the fuel sheaths could not be carried out due to lack of data.

The Sb-124 inventories on steam generator tubes, and end fittings (both bodies and liners) were estimated to be about 3 Ci and 5 Ci, respectively, based on data on a Bruce 2 steam generator tube removed in 1981/7/ and Bruce 2 end fitting liners/8/.

The above results summarized in Table 2 show that the Sb-124 inventory on a Bruce reactor is about 1100 Ci. However, it should be noted that the Sb-124 inventory may well be very different from one unit to another unit, for example Sb-124 was not detected at the Pickering 3 reactor face before the 1985 CAN-DECON/9/, but was detected in other Pickering A reactors before the decontaminations. This could be due to differences in the antimony content of the base metal or differences in the transport behaviour of materials to the core and from the core after activation.

3. BEHAVIOUR OF Sb-124 DURING CAN-DECON

To monitor the change in Sb-124 activity during the CAN-DECON decontamination, more than sixty cruds from the recent Bruce decontamination were analyzed. In addition, the data on Sb-124

during several decontaminations were gathered and summarized below.

3.1 Bruce Unit 1 1986 CAN-DECON

The radioactivities in the cruds from the Bruce Unit 1 CAN-DECON decontamination were measured/10/. The specific activities of several isotopes were then calculated. In cases where the initial weight of filters was not known an average value of 13 blank filters was used in the calculation.

The results shown in Table 3 and Figure 1 indicate that the specific activities of fission products and activation products of cruds were very high initially then reached steady values after about 4 h of decontamination. At the same time, the crud level in solutions increased from 6 to 20 mg/l. This suggests that some highly active crud which was most likely from the core was released very briefly and then was diluted by cruds with lower specific activity from other part of the circuit or by materials resulting from reactions with the reagents.

To confirm that the highly active cruds were released from the core, three cruds were examined by Auger/11/. On the crud collected at 1.25 h after the first chemical injection, large particles of zirconium dioxide (ZrO_2) and smaller particles of magnetite were found (Figure 2, the bright particle is zirconium dioxide because of charging). The small various-sized particles contained mostly oxygen and tin. No zirconium dioxide and tin, and mainly magnetite were found on the crud collected at 10.25 h and 60.75 h/11/. The presence of zirconium and tin in the cruds suggests that the initial oxide originated from the pressure tubes and fuel sheaths.

Furthermore, using XRF/12/ zirconium was also found on the cruds collected at 0.5 and 1.25 h, but not on cruds collected at 1.75, 2.75 and 3.25 h indicating that the release of zirconium ceased before 1.75 h. The weight of zirconium dioxide on the cruds collected at 0.5 & 1.25 h was estimated to be about 6% & 9% of the weight of magnetite, respectively. Since the highly active oxides were released briefly during the early stage of decontamination and zirconium dioxide is known to be not easily dissolved in dilute acid, the above result seems to indicate that the zirconium dioxide found on the cruds was originally 'loosely' deposited on the pressure tubes or fuel sheaths.

As indicated above the core is not the only contributor of Sb-124 during decontamination. This is also supported by the observation that the total amount of Sb-124 collected on the cruds during the initial 2.25 h could only account for about one-eighth of the total amount collected before the

mixed bed resin was valved in, and the gradual rise of Sb-124 activity at the reactor face/13/ did not reflect the brief release of cruds from the core. The decrease of Sb-124 activity at the boiler/13/ indicates Sb-124 also originates from the boiler.

Once the specific activities of the cruds reached steady values they did not seem to change considerably during the decontamination. However, the radioisotope specific activity of cruds increased soon after the mixed bed ion exchange column was valved in. (This phenomenon was also observed in the previous decontaminations). This could be due to the increase of pH of the solution which in turn lowers the solubility of the isotopes, or a brief release of highly active crud resulting from the sudden change in pH, or the decrease of non-active corrosion products (eg ferrous oxalate) in the cruds. In addition, the increase of specific activity of Fe-59, Zr-95, Sb-124 and Ce-144 appeared to be faster than those of Ru-103 and Co-60 (Table 3).

It was also observed that

a. the crud level dropped considerably between 30 and 57 h of the decontamination when the reagent was not regenerated by the ion exchange columns (pH was about 6.7) suggesting that the original level of crud resulted from the chemical reaction of the reagents. The increase of Sb-124 specific activity in the crud during this period possibly resulted from the rise in pH which lowered the Sb-124 solubility.

b. Sb-124 in solution was initially 8 μCi/kg and then dropped to a steady value of about 1.5 μCi/kg after 7 h /13/.

c. Although the Sb-124 specific activity of the cruds dropped by a factor of about ten during the decontamination, the antimony (both active and non-active) content of five cruds determined by NAA/14/ changed by a factor of about 2.5 (from 50 to 20 ppm) once again suggesting that in-core materials are not the only source of antimony. However, this antimony content result was only a very rough estimate due to high background signals from the other isotopes present in the cruds.

d. The Co-60 to iron ratio of the crud collected at 74, 76 & 79 h (the mixed bed ion exchange column was already valved in) was 0.11, 0.10 & 0.08 Ci/kg, respectively /15/.

e. Antimony and tin concentrations on a post-CAN-DECON in-service carbon steel coupon were found to be below two atomic percent by Auger/16/.

3.2 Pickering Unit 3 1985 CAN-DECON

Sb-124 was not observed at the Pickering 3 reactor face before the decontamination and no significant Sb-124 re-deposition on the reactor face was observed during the decontamination /9/.

3.3 Pickering Unit 1 1984 CAN-DECON

During this decontamination the Sb-124 field at boiler 10 decreased whereas the Sb-124 field increased at the reactor face (East)/17/ indicating Sb-124 could also originate from the boiler.

3.4 Pickering Unit 1 1983 CAN-DECON/18/

a. Sb-124 deposition was also observed during this decontamination when no boilers were in the flow path. This seems to suggest that Sb-124 could not have originated from the oxide on the boilers. However, in order to save outage time Li removal was begun about one shift before the decontamination with all boilers in the flow path. It is possible that the Sb-124 was mobilized from the boilers during the Li removal when the pH of the coolant was lowered to around 7 (see section 3.7).

b. Sb-124 in solution was initially about 10 μCi/kg then dropped to 0.6 μCi/kg in 7 h.

c. Crud concentration peaked at 54 mg/kg and dropped to <1 mg/kg in 5 h. No data were available after 10 h.

3.5 Pickering Unit 1 1981 CAN-DECON/19/

a. Sb-124 in solution dropped by at least a factor of 2 after passing through the filter suggesting at least half of the Sb-124 was in particulate form.

b. Sb-124 concentration at the cation exchange inlet was the same as the concentration at the ion exchange column outlet indicating that soluble Sb-124 could not be removed from solution by cation exchange resin.

c. Sb-124 in solution initially was about 10 μCi/kg and dropped to about 1.5 μCi/kg in 7 h (total duration of the decontamination was 13 h).

d. Sb-124 (and other radioisotopes) dropped abruptly from an initial value of 100 mCi/kg of crud (between 0200 to 0400 h) to a steady value of 10 mCi/kg. (During this period the crud release increased suddenly then dropped). This suggested the initial crud with high Sb-124 specific activity was diluted with the ones with lower specific activity (probably ferrous oxalate).

   The specific activity of Sb-124 on Pickering 2 boiler hinges removed in 1983 ranged from 2 to 10 mCi/kg and the specific activity of Sb-124 on carbon steel coupons removed before this CAN-DECON ranged from 2 mCi/kg (fixed oxide) to 57 mCi/kg (loose oxide). This suggests that the lower specific activity crud could possibly be released from the carbon steel surfaces.

e. Using Auger microanalysis a thin layer of antimony, copper and tin (in apparently elemental forms) was found on a carbon steel coupon removed after the decontamination /20/. This suggests that these elements (which most likely came from the Monel 400 boiler tubes) were plated out onto oxide surfaces during CAN-DECON/20/.

3.6 Summary of Corrosion Coupon Results

Corrosion coupon data from various decontaminations were reviewed. It was found that a lower decontamination factor (DF) for Sb-124 was generally obtained for the in-service carbon steel and 410 SS coupons (Table 4) suggesting that Sb-124 selectively deposits on the carbon steel and 410 SS instead of Monel 400. In addition, among the carbon steel, 410 SS and Monel 400 polished coupons installed just prior to the decontamination, more Sb-124 was usually found on the carbon steel coupons. The amount of Sb-124 on the polished carbon steel coupons varied considerably from one decontamination to another - the ones from the Pickering 1 1981 decontamination had the highest Sb-124 surface activity, and those from the Pickering 2 April 1984 and Pickering 3 1985 had the lowest Sb-124 activity.

3.7 Literature Survey

A brief literature survey located only one publication on the transport of Sb-124 in an out-reactor recirculating water loop at CRNL/21/. It was found that as the temperature was increased from 60° C to 280° C (at neutral pH) antimony was rapidly desorbed from a reservoir within the loop and finally was deposited uniformly throughout the system. It was suggested that the deposition process was due to the precipitation of magnetite caused by its decreased solubility at higher temperature and neutral pH. The desorption of antimony was also supported by the fact that antimony becomes ineffective as an adsorption type

pickling inhibitor above about 200° C/21/. The desorption of antimony was also demonstrated by the removal of Sb-124 from previously cold surfaces by a high temperature inactive stream.

The effect of pH on the Sb-124 on the test section at 300° C was also studied/21/. No change in activity was found when the pH was altered from neutral to 10.5 by adding LiOH. However, when the pH was reduced to 4.5 by adding nitric acid, a sharp drop in Sb-124 activity occurred during the initial stage of the pH decrease, followed by a small gradual rise. Again, the solubility of magnetite was suggested as the contributing factor because at 300° C a pH increase from neutral to 10.5 has little effect, a reduction from 10.5 to 4.5 increases solubility considerably/21/. Therefore, the distribution of Sb-124 activity in coolant circuits is very sensitive to changes in coolant temperature and pH.

Recently a paper on the behaviour of antimony was presented at the Water Chemistry for Nuclear Reactor Systems Conference /22/. It was reported that during the preparation for shut down in Biblis, as the Li concentration was reduced and the pH changed from 7.4 to 6.8, no influence on the mobilization of antimony was observed (the activities in the coolant remained constant). But further reduction of Li to < 1 ppm and pH to < 6.4 effected an immediate partial release of antimony. It was indicated that the mobilized antimony was kept in solution and transported to the clean-up system. The major release of antimony from the fuel element surfaces took place after shut down by injection of boric acid (pH was 4.5 at the end of boration) and the Sb-124 activity on the pipe walls increased.

These findings agree with the observations during the CAN-DECON decontaminations that the desorption of Sb-124 activity occurred essentially after the first chemical injection (as the pH was lowered). Unfortunately, no data were available to determine whether Sb-124 mobilization also occurred during the last stage of Li removal.

3.8 Summary

a. High specific activity crud (containing Sb-124 and other isotopes) is released during the initial stage of a decontamination. The presence of zirconium dioxide and tin in the crud indicated the crud originated from the pressure tubes and fuel sheaths. Since the release of zirconium dioxide is very brief and zirconium dioxide is known to be very insoluble in dilute acid, it is likely that the highly active crud was originally loosely deposited on the pressure tubes or fuel sheaths.

Then the highly active crud was diluted by cruds with lower specific activity from the boilers or other part of the circuit, or by materials resulting from reactions with the reagents. The Sb-124 activity of cruds reaches a steady value after several hours.

b. It has been reported that mobilization of Sb-124 was observed when the pH was below 6.4 in a laboratory test loop and the distribution of Sb-124 activity in the coolant circuit was very sensitive to changes in coolant temperature and pH/21/. Similar findings were reported from Biblis/22/.

c. The specific activities of various fission products, activated products as well as Sb-124 in cruds increase soon after the mixed bed ion exchange column is valved in.

d. A significant fraction of the Sb-124 is in particulate form and can be removed by filtration, but soluble Sb-124 (most likely present as antimonates) can not be removed by cation exchange resin during CAN-DECON.

e. Corrosion coupon results showed that Sb-124 was most likely to deposit on the carbon steel and 410 SS surfaces rather than on the Monel 400 during a Pickering decontamination.

CONCLUSIONS

1. Antimony and tin were found on most of the PHT specimens. The amounts of Sb-124 and Sb-125 on the specimens indicate that the major source of Sb-124 in a CANDU reactor is from the neutron activation of Sb-123 present in the in-core materials. The Sb-123 in the corrosion products released from other parts of the circuit, eg from boilers, could also be activated in the core. Cruds containing Sb-124 could subsequently deposit onto other PHT surfaces.

2. The inventory of Sb-124 in a Bruce reactor was estimated to be about 1100 Ci, however, this may well vary from one unit to another unit.

3. Highly active crud containing Sb-124 and other fission products etc is released briefly from the core soon after the first chemical injection in a CAN-DECON decontamination. In addition, Sb-124 is also released from boilers during the decontamination.

4. Sb-124 can be partly retained by the CAN-DECON filter, but not by the cation exchange resin.

5. Corrosion coupon results showed that Sb-124 was most likely to deposit on the carbon steel and 410 SS surfaces rather than on the Monel 400 during a Pickering decontamination.

6. It has been found that the distribution of Sb-124 activity in a coolant circuit was very sensitive to changes in coolant temperature and pH in a CRNL test loop/21/.

RECOMMENDATION

Although the Co-60 radiation field at the reactor face significantly decreased after the 1981 Pickering 1 and 1986 Bruce 1 decontaminations, the deposition of Sb-124 on various PHT surfaces increased the radiation field to the extent that the overall radiation fields almost remained unchanged after the decontamination. Therefore, Sb-124 plays a major role in determining the overall effectiveness of a CAN-DECON decontamination in man-rem reduction for the subsequent maintenance work near the reactor face. It is important that research on methods to mobilize Sb-124 from PHT surfaces (before or after a decontamination) and subsequent removal of Sb-124 from the coolant be given high priority. The project should include (i) studying the behaviour of Sb-124 during Li removal in the laboratory as well as in the field, (ii) investigating the feasibility of using a high temperature coolant stream (at neutral pH) to mobilize Sb-124 from a cold surface, and (iii) studying the use of anion exchange (or mixed bed ion exchange) resins together with particulate filters to cleanup the coolant containing Sb-124.

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TABLE 1

THE ANTIMONY AND TIN CONTENT IN VARIOUS MATERIALS (ppm)

	Antimony		Tin	
	Calculated*	Analyzed	Calculated*	Analyzed
Zircaloy 2	40		21000	
Zirconium/ 2.5% Niobium	7	1 - 3		< 20
Zircaloy 4		2		7000
410 SS	200	30		50
403 SS		60		50
Carbon steel (A106 Grade B)		100		< 10
Inconel 600		4000		< 10

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* The calculation was based on observed activities on the sample.

TABLE 2

AN ESTIMATE OF THE INVENTORY OF ANTIMONY-124 IN A BRUCE REACTOR

Pressure Tubes	
Base metal	740 Ci
Oxide	9 Ci
Fuel Sheaths	
Base metal	350 Ci
Oxide	unknown
End Fittings (not including the inner surface of liners)	3 Ci
Steam Generator Tubes	5 Ci

Refer to Section 2 for assumptions used in the estimate.

TABLE 3

THE SPECIFIC ACTIVITIES OF VARIOUS ISOTOPES IN CRUD COLLECTED DURING THE 1986 BRUCE UNIT 1 CAN-DECON

Date	Time	Elapsed Time, h	mg Weight	Specific Activity, mCi/kg Co-60	Sb-124	Sb-125	Ce-144	Fe-59	Ru-103	Zr-95	pH
SEP 3	2200	-10.5	0.5 ?	186.0	652.0	32.0	64.0	0.0	0.0	1748.0	11.1
SEP 4	900	0.5	6.19	154.4	140.7	14.7	120.5	31.3	62.2	3563.8	6.4
SEP 4	945	1.25	10.45 ?	201.3	226.9	27.7	131.8	38.6	62.7	4077.5	6.3
SEP 4	1015	1.75	8.98 ?	151.0	164.1	28.4	119.8	35.9	39.9	3681.5	6.3
SEP 4	1045	2.25	12.78 ?	111.0	121.4	21.1	86.3	19.8	34.8	2420.2	6.3
SEP 4	1115	2.75	12.57 ?	85.2	78.4	11.1	55.8	20.4	24.0	1659.5	6.3
SEP 4	1145	3.25	14.53	51.5	42.3	5.1	27.9	12.8	16.0	845.1	6.2
SEP 4	1215	3.75	20.75 ?	36.8	27.5	4.3	16.6	10.3	10.8	464.7	5.9
SEP 4	1245	4.25	19.92	27.4	20.2	3.4	11.8	6.8	7.4	341.1	6.0
SEP 4	1315	4.75	23.4	24.4	20.6	4.7	11.7	6.2	8.5	326.9	5.5
SEP 4	1345	5.25	23.17	22.3	18.6	4.4	11.1	5.7	6.0	281.9	6.1
SEP 4	1415	5.75	22.6	24.7	22.2	5.0	11.6	5.6	7.6	284.4	5.8
SEP 4	1440	6.17	22.34	20.8	17.1	3.1	8.1	4.9	6.4	214.9	6.1
SEP 4	1515	6.75	16	23.1	18.8	3.8	9.3	4.6	6.5	242.1	6.1
SEP 4	1545	7.25	19.05	21.0	16.9	3.7	8.2	4.5	5.9	199.1	6.1
SEP 4	1615	7.75	21.16	32.0	27.7	3.9	11.5	6.4	11.4	259.1	5.9
SEP 4	1645	8.25	36	17.4	13.7	1.6	5.8	3.4	5.6	135.5	6.0
SEP 4	1715	8.75	23.35	27.2	20.2	2.4	8.0	5.6	8.3	196.8	5.9
SEP 4	1725	8.92	14.54	36.4	29.8	3.5	11.3	6.2	10.6	233.5	5.9
SEP 4	1745	9.25	20.46	30.9	21.8	2.9	9.8	4.7	8.8	206.0	5.9
SEP 4	1815	9.75	21.17	30.0	23.1	0.0	9.6	5.4	9.2	214.5	5.8
SEP 4	1845	10.25	19.57	29.6	21.1	2.6	9.9	5.4	8.8	201.7	6.0
SEP 4	2015	11.75	21.6	31.9	28.8	3.6	9.5	5.2	9.6	210.8	5.5
SEP 4	2115	12.75	23.19	31.2	27.6	5.1	12.1	5.2	11.2	246.7	5.8
SEP 4	2245	14.25	32.79	29.3	21.7	4.2	11.9	5.4	10.9	246.2	5.8
SEP 4	2315	14.75	31.39	31.4	21.8	4.4	10.1	6.5	10.6	264.8	6.2
SEP 5	15	15.75	31.86	28.6	19.3	3.8	12.0	6.0	9.5	243.0	6.1
SEP 5	100	16.5	26.66	27.7	18.9	3.8	11.3	5.9	9.2	250.1	6.3
SEP 5	205	17.67	19.24	29.2	18.7	3.7	11.6	5.8	9.7	275.4	6.3
SEP 5	300	18.5	23.24 ?	34.3	26.7	6.0	15.3	6.8	11.9	332.2	5.8
SEP 5	400	19.5	25.28 ?	29.4	22.1	2.5	11.6	6.8	11.0	299.8	5.9

? = The weight of the filter before filtration was not known, an average value of a blank filter was used in the calculation

TABLE 3 (cont'd)

Date	Time	Elapsed Time, h	mg Weight	Specific Activity, mCi/kg Co-60	Sb-124	Sb-125	Ce-144	Fe-59	Ru-103	Zr-95	pH
SEP 5	530	21	21.46 ?	35.8	26.6	5.2	17.2	7.7	12.7	422.9	5.6
SEP 5	1145	27.25	24.92	24.5	14.6	3.3	13.7	5.7	8.5	359.8	5.8
SEP 5	1215	27.75	20.77	25.5	16.9	4.4	15.4	5.5	9.7	395.4	5.5
SEP 5	1245	28.25	19.97	28.5	18.7	3.5	14.9	6.4	11.2	437.3	5.1
SEP 5	1315	28.75	23.94	28.9	22.5	5.3	18.1	5.9	13.1	451.5	5.4
SEP 5	1345	29.25	31.47	28.0	21.0	5.2	18.0	6.5	11.9	450.9	5.3
SEP 5	1415	29.75	43.08	26.0	17.6	2.7	16.8	5.4	10.3	380.5	5.6
SEP 5	1445	30.25	25.98	20.9	16.5	4.0	17.7	4.3	11.3	407.6	5.9
SEP 5	2030	36	21.88 ?	38.0	54.8	6.9	20.1	7.9	10.4	538.8	6.8
SEP 6	105	39.58	9.57 ?	35.5	49.6	6.5	23.8	6.2	12.4	583.8	7.0
SEP 6	415	43.75	5.14	42.0	42.0	0.0	11.7	4.9	10.1	279.4	6.9
SEP 6	1715	56.75	1.99	28.1	23.1	4.0	14.6	5.5	15.6	274.4	6.7
SEP 6	1745	57.25	3.02	31.8	31.1	5.6	17.5	5.0	33.4	402.0	6.3
SEP 6	1815	57.75	17.55	25.9	23.1	5.0	18.7	4.3	21.2	484.3	5.6
SEP 6	1845	58.25	18.16	22.1	15.0	3.7	14.9	4.0	16.3	385.1	5.5
SEP 6	1945	59.25	16.54	22.0	14.0	3.7	14.1	3.5	15.2	324.2	5.8
SEP 6	2020	59.83	15.16	23.7	13.3	3.4	12.5	3.4	15.1	312.6	5.8
SEP 6	2045	60.25	16.16	23.8	10.4	3.2	10.6	3.1	13.6	281.3	5.5
SEP 6	2115	60.75	15.67	23.4	11.3	3.3	13.0	3.3	14.2	301.1	5.0
SEP 6	2145	61.25	8.6	24.1	11.5	2.8	13.8	3.3	20.5	289.4	5.0
SEP 6	2215	61.75	23.66	24.6	13.1	2.1	11.5	3.3	14.3	273.4	5.1
SEP 6	2245	62.25	27.27	25.9	12.8	2.9	12.1	3.2	12.9	248.4	5.2
SEP 6	2315	62.75	23.48	25.5	12.5	4.5	13.6	3.2	12.8	255.5	5.2
SEP 6	2345	63.25	23.03	25.5	11.7	3.7	12.4	3.0	12.0	240.4	5.2
SEP 7	15	63.75	22.14	26.6	11.7	3.7	10.8	3.0	11.2	234.2	5.3
SEP 7	45	64.25	22.19	26.7	11.2	3.9	11.1	3.3	12.3	251.7	5.2
SEP 7	115	64.75	25.35	25.9	11.1	3.0	11.6	3.1	11.5	241.9	5.2
SEP 7	145	65.25	24.08	26.5	10.7	2.8	10.5	3.9	11.6	240.4	5.3
SEP 7	330	67	26.37	28.8	15.1	3.4	15.1	5.2	14.8	353.4	5.9
SEP 7	530	69	13.58	35.9	22.3	4.8	25.6	6.7	22.1	643.7	6.6
SEP 7	630	70	10.18	45.2	26.0	7.9	35.3	8.9	28.6	903.2	6.5
SEP 7	830	72	4.46	57.4	42.6	13.0	55.2	14.3	25.1	1520.0	6.9
SEP 7	930	73	3.29	60.8	50.8	14.6	49.2	16.1	31.3	1591.8	6.9
SEP 7	1030	74	3.24	55.6	48.1	11.7	56.8	14.5	25.3	1459.3	6.7
SEP 7	1130	75	2.85	58.9	56.8	16.5	63.9	13.7	26.0	1491.2	6.9
SEP 7	1230	76	2.52	54.4	56.7	17.1	65.1	14.7	17.5	1369.0	6.7

? = The weight of the filter before filtration was not known, an average value of a blank filter was used in the calculation

TABLE 4

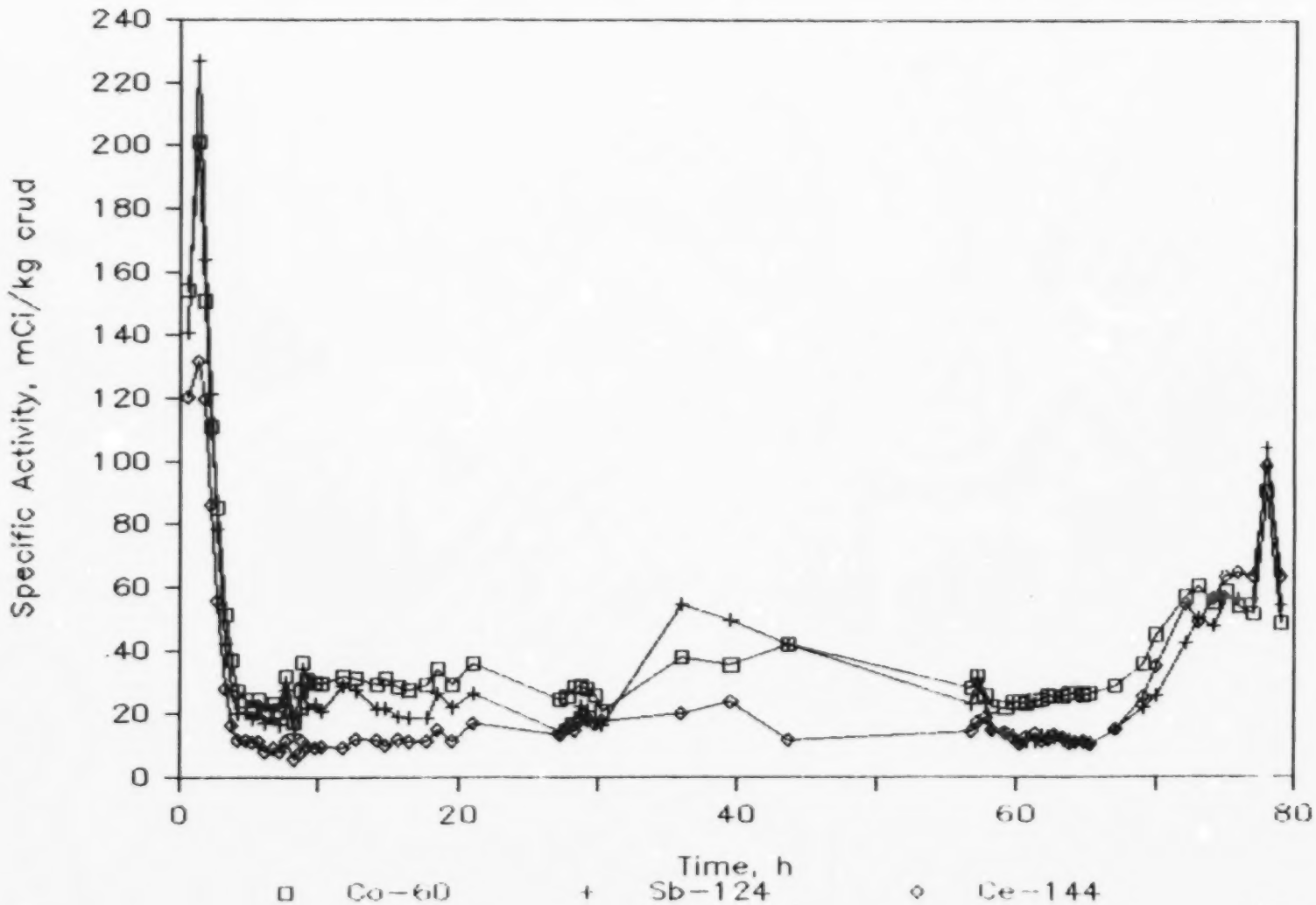
THE DECONTAMINATION FACTORS (DF's) FOR Sb-124 DETERMINED FROM COUPONS REMOVED BEFORE AND AFTER CAN-DECON

Reactor	Exposure History of Coupons	Material	DF
Pickering 1	81 CAN-DECON	CS	0.01
		ML	0.03
Pickering 1	81 & 84 CAN-DECON	CS	0.7
		410 SS	1.2
Pickering 2	Jan & Apr 1984 CAN-DECON	CS	1.2
		410 SS	0.6
		ML	2.3
Pickering 3	86 CAN-DECON	ML	3.4
Pickering 4	86 CAN-DECON	CS	0.05
		410 SS	0.01
		ML	0.3

CS = Carbon Steel
ML = Monel 400

Figure 1

The Specific Activities of Ce-144, Co-60 and Sb-124
on the Cruds Collected During the Bruce 1 CAN-DECON



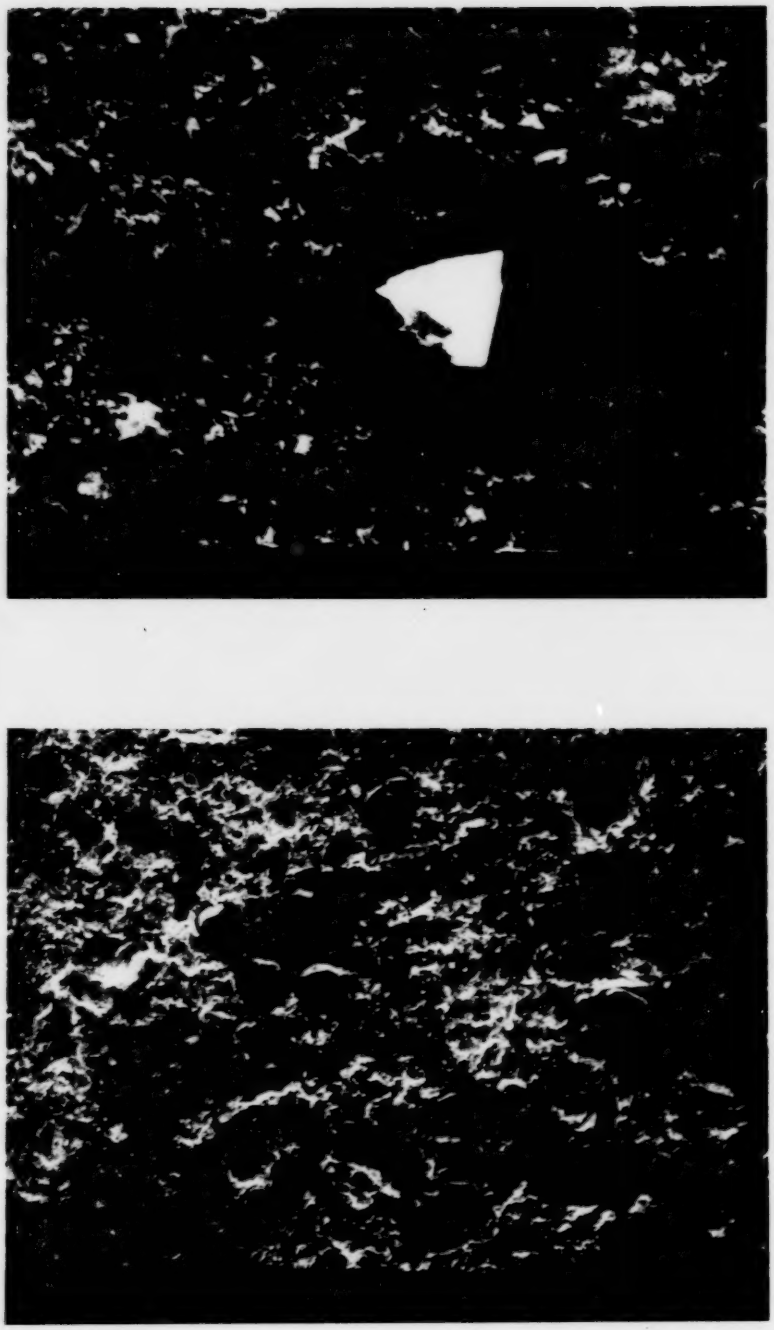


Figure 2

Scanning Electron Micrographs of the Crud Collected During the Bruce 1 CAN-DECON on September 4, 1986, 0945

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